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ORIGINAL RESEARCH ARTICLE

Transforming Science Classrooms into Health-Literate Ecosystems: A Systematic Instructional Review of K–12 Pedagogical Strategies

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ABSTRACT

Modern science education increasingly demands an instructional paradigm shift that bridges classroom concepts with authentic, real-life contexts, particularly concerning critical health decision-making among adolescents. However, a comprehensive structural mapping of how health literacy is systemically integrated into science instructional designs remains scarce. [Objective] This systematic review aims to comprehensively synthesize the instructional strategies, integrated science topics, and pedagogical outcomes of embedding health literacy within the school science curriculum. [Method] Adopting the PRISMA 2020 protocol integrated with the qualitative-sensitive SPIDER framework, 30 empirical articles published between 2017 and 2026 were rigorously screened and extracted from Scopus, ERIC, and SINTA databases. [Results] The thematic synthesis reveals that health literacy integration is predominantly implemented at the secondary school level using mixed-methods and quasi-experimental designs. Prominent instructional approaches include project-based learning, inquiry-based models, and advanced digital media interventions (such as virtual reality, educational websites, and social media platforms) applied across critical topics like nutrition, reproductive health, mental well-being, and infectious disease prevention. While these socio-scientific instructional designs consistently yield profound advancements in students' health-related knowledge and critical awareness, achieving sustainable, long-term health behavior changes remains a pervasive challenge. [Conclusion] This study concludes that effective health integration requires a transition from temporary pedagogical interventions to permanent, curriculum-wide instructional models. Future research must prioritize the validation of standardized K–12 health literacy assessment instruments and longitudinal investigations in resource-limited educational settings.

ABSTRAK

Pendidikan sains modern semakin menuntut pergeseran paradigma pengajaran yang menjembatani konsep kelas dengan konteks kehidupan nyata yang otentik, khususnya mengenai pengambilan keputusan kesehatan yang kritis di kalangan remaja. Namun, pemetaan struktural komprehensif tentang bagaimana literasi kesehatan diintegrasikan secara sistematis ke dalam desain pengajaran sains masih langka. [Tujuan] Tinjauan sistematis ini bertujuan untuk mensintesis secara komprehensif strategi pengajaran, topik sains terintegrasi, dan hasil pedagogis dari pengintegrasian literasi kesehatan dalam kurikulum sains sekolah. [Metode] Dengan mengadopsi protokol PRISMA 2020 yang terintegrasi dengan kerangka kerja SPIDER yang sensitif terhadap kualitas, 30 artikel empiris yang diterbitkan antara tahun 2017 dan 2026 disaring secara ketat dan diekstrak dari basis data Scopus, ERIC, dan SINTA. [Hasil] Sintesis tematik mengungkapkan bahwa integrasi literasi kesehatan sebagian besar diimplementasikan di tingkat sekolah menengah menggunakan metode campuran dan desain kuasi-eksperimental. Pendekatan pengajaran yang menonjol meliputi pembelajaran berbasis proyek, model berbasis penyelidikan, dan intervensi media digital canggih (seperti realitas virtual, situs web pendidikan, dan platform media sosial) yang diterapkan pada topik-topik penting seperti nutrisi, kesehatan reproduksi, kesejahteraan mental, dan pencegahan penyakit menular. Meskipun desain pengajaran sosio-ilmiah ini secara konsisten menghasilkan kemajuan yang mendalam dalam pengetahuan dan kesadaran kritis siswa terkait kesehatan, mencapai perubahan perilaku kesehatan jangka panjang yang berkelanjutan tetap menjadi tantangan yang meluas. [Kesimpulan] Studi ini menyimpulkan bahwa integrasi kesehatan yang efektif membutuhkan transisi dari intervensi pedagogis sementara ke model pengajaran permanen di seluruh kurikulum. Penelitian di masa mendatang harus memprioritaskan validasi instrumen penilaian literasi kesehatan K–12 yang terstandarisasi dan investigasi longitudinal di lingkungan pendidikan dengan sumber daya terbatas.

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Keywords: health literacy, science education, instructional design, systematic literature review, socio-scientific issues.

INTRODUCTION

The 21st century has brought a profound paradigm shift in science education at the international level, transitioning from rote memorization of abstract facts to the development of actionable competencies grounded in real-life contexts (Mceuen et al., 2025; Osborne, 2024). Global benchmarks, such as the Programme for International Student Assessment (PISA) and updated science curriculum frameworks, explicitly dictate that successful science instruction must integrate conceptual, procedural, and epistemic dimensions to empower students to make informed decisions regarding real-world challenges (OECD, 2023; Wajdi et al., 2024). A crucial but frequently overlooked dimension of this scientific literacy is health literacy, which represents an individual's cognitive and social motivation to access, understand, appraise, and apply health information to maintain systemic well-being (Broder et al., 2021; Sørensen et al., 2020). In modern society, school science classrooms have emerged as the most strategic, structured, and equitable ecosystems to foster these life-saving competencies from an early age (Molina et al., 2023; Zubiani et al., 2023). However, a major global challenge persists as educational systems often treat health education as an isolated biological topic or an extracurricular afterthought rather than a core instructional pillar of natural science education (Morrow et al., 2025; Smart et al., 2025). This institutional division isolates scientific concepts from the authentic health decisions students face daily, compromising both their scientific agency and their public health literacy (Mendes et al., 2021; Santos et al., 2022).

The critical necessity of bridging this gap is underscored by severe public health crises and worsening lifestyle trends among the global youth population (Pagnini et al., 2021; WHO, 2022). According to international consensus reports, contemporary adolescents exhibit alarming behavioral patterns, including the excessive consumption of ultra-processed foods and items high in sugar, salt, and fat, alongside a high vulnerability to digital misinformation regarding infectious diseases and vaccines (Kasim et al., 2025; WHO, 2022). This widespread vulnerability is a direct manifestation of deficient health literacy, where students lack the critical appraisal skills required to evaluate health claims, interpret nutritional data, or decipher public health guidelines (Prasetyo et al., 2025; Tomás-Folch et al., 2023). Formal K–12 schooling represents the sole societal ecosystem capable of delivering systematic, equity-driven health interventions to diverse demographic populations (Enriquez et al., 2021; Pierce et al., 2026). Despite this

immense potential, curriculum developers and science teachers face massive pedagogical barriers, including rigid instructional designs, a lack of specialized pedagogical training, and a scarcity of validated materials that seamlessly blend health contexts with core physical and biological science standards (Lupton & Turner, 2023; Wajdi et al., 2024). Consequently, science education remains largely disconnected from urgent socio-scientific imperatives, leaving students unprepared to navigate complex medical and health environments (Mceuen et al., 2025; Smart L. R. et al., 2025).

A substantial body of empirical literature has emerged to address these pedagogical challenges, with researchers actively examining various facets of health integration within educational settings (Morrow et al., 2025; Zakaria et al., 2025). Empirical investigations regarding instructional media interventions have been heavily documented, including web-based learning platforms by Wajdi et al. (2024), TikTok digital video applications for dental health by Zakaria et al. (2025), and immersive virtual reality environments for psychological well-being by Zynda et al. (2022). Concurrently, research regarding immersive school-based programs and specialized curricula has been conducted, such as open schooling vaccine programs by Mceuen et al. (2025), community-based genomic frameworks by Molina et al. (2023), and targeted pain science education events by Morrow et al. (2025) and Smart et al. (2025). Furthermore, studies evaluating specific dietary, lifestyle, and physiological interventions are highly prevalent, including adolescent club frameworks by Sitati et al. (2020), observational photoaging feasibility treatments by Ridout et al. (2022), school culinary skills initiatives by Tomás-Folch et al. (2023), and structural health frameworks by Pierce et al. (2026). Finally, foundational research regarding diagnostic assessments and baseline profiles has been pursued, including school dietary surveys by Pagnini et al. (2021), collaborative basic science evaluations by Hadjimarcou et al. (2020), nutritional health literacy profiling by Prasetyo et al. (2025), metacognitive drinking guidance by Yılmaz et al. (2020a), and system adaptation tests by Yılmaz et al. (2020b).

Despite the volume of these studies, a rigorous critical evaluation reveals severe methodological and conceptual limitations within the existing research landscape (Morrow et al., 2025; Wajdi et al., 2024). The digital intervention studies by Wajdi et al. (2024) and Zakaria et al. (2025) focus heavily on immediate, short-term knowledge gains while completely ignoring long-term behavior retention, a flaw compounded by Zynda et al. (2022) whose virtual reality setups suffer from low ecological validity and high resource dependence. Immersive curricular models like those by Mceuen et al. (2025) and Molina et al. (2023) are exceptionally difficult to scale, as they rely on costly university partnerships and intensive expert presence that regular K–12 schools cannot afford. Similarly, the short-term instruction models evaluated by Morrow et al. (2025) and Smart et al. (2025) fail to track whether the shifts in psychological pain beliefs translate into everyday coping mechanisms. Lifestyle interventions by Sitati et al. (2020) and Pierce et al. (2026) exhibit extreme contextual specificity, making their findings ungeneralisable to diverse cultural or under-resourced regions, whereas the culinary modules by Tomás-Folch et al. (2023) and the appearance-focused designs by Ridout et al. (2022) prove logistically exhausting for standard teaching staff. Lastly, descriptive surveys and diagnostic assessments by Hadjimarcou et al. (2020), Prasetyo et al. (2025), and both studies by Yılmaz et al. (2020a, 2020b) provide static, observational data that capture baseline vulnerabilities but offer no actionable, experimental solutions for systemic pedagogical execution.

Consequently, these collective shortcomings create a pronounced research gap that hinders the advancement of health-integrated science education (Lupton & Turner, 2023; Mceuen et al., 2025). There is a complete absence of a comprehensive, structural mapping that systemically synthesizes these fragmented pedagogical approaches, leaving curriculum developers without a unified framework to understand which instructional strategies work best for specific science topics (Pierce et al., 2026; Wajdi et al., 2024). Prior reviews remain confined to traditional, rigid biological boundaries or focus exclusively on health as a clinical entity, completely overlooking its dimension as an instructional and pedagogical catalyst within natural science classrooms (Molina et al., 2023; Smart L. R. et al., 2025). Furthermore, a significant context gap exists, as the vast majority of these experimental interventions are anchored in wealthy, developed nations with highly sophisticated laboratory infrastructures, creating a severe shortage of empirical evidence regarding how health literacy can be realistically embedded within under-resourced schools in developing countries (Prasetyo et al., 2025; Zakaria et al., 2025). There is also a major instrument gap, characterized by a lack of standardized, validated psychometric tools tailored to measure functional, communicative, and critical

health literacy dimensions across the K–12 spectrum (Yılmaz et al., 2020b; Zubiani et al., 2023). By failing to通 synthesize the cross-study relationships between instructional tactics, specific health contexts, and cognitive outcomes, existing literature leaves a critical void regarding how to transform fragmented, short-term classroom interventions into permanent, curriculum-wide educational models (Morrow et al., 2025; Tomás-Folch et al., 2023).

The novelty of this study lies in its systemic instructional approach, which re-conceptualizes health literacy from a simple biological topic into a dynamic, cross-cutting pedagogical vehicle within K–12 science education (Mceuen et al., 2025; Pierce et al., 2026). Unlike conventional systematic reviews that treat health and science as separate curricular entities, this research provides a unified, structural synthesis that decodes the precise intersection between instructional strategies and core scientific domains (Morrow et al., 2025; Wajdi et al., 2024). By breaking away from traditional, isolated topic analyses, this review introduces a comprehensive mapping of modern pedagogical innovations—ranging from youth participatory action research and socio-scientific reasoning to advanced gamification and immersive virtual reality (Molina et al., 2023; Zynda et al., 2022). Furthermore, this study is the first to explicitly contrast high-resource educational frameworks against the realities of under-resourced settings, exposing systemic implementation gaps that have been ignored in mainstream literature (Prasetyo et al., 2025; Zakaria et al., 2025). It systematically uncovers how specific instructional variables directly influence different tiers of literacy, specifically evaluating why certain designs succeed in boosting academic knowledge but fail to generate lasting health behavior changes. This meta-pedagogical focus offers a fresh conceptual blueprint that bridges the historical divide between public health interventions and formal school science instruction.

To establish a rigorous analytical foundation, this systematic review is guided by the multidimensional Health Literacy Model developed by Sørensen et al. (2020) alongside the Socio-Scientific Issues (SSI) pedagogical framework (Mceuen et al., 2025; Osborne, 2024). The updated Sørensen et al. (2020) model provides an essential blueprint for deconstructing literacy into four consecutive cognitive stages: the ability to access, understand, appraise, and apply health-related information across healthcare, disease prevention, and health promotion domains. This overarching framework is explicitly paired with the SSI approach, which dictates that science instruction achieves maximum cognitive engagement when structured around real-world, socially relevant, and ethically complex controversies (Sadler & Zeidler, 2021; Wajdi et al., 2024). In this study, health dilemmas—such as vaccine hesitancy, nutritional choices, and epidemic containment—are treated not as isolated clinical data, but as authentic scientific contexts that require the application of evidence-based reasoning (Mceuen et al., 2025; Pagnini et al., 2021). By synthesizing literature through this combined theoretical lens, the review evaluates how different classroom teaching strategies support or hinder a student's progression through the cognitive stages of the Sørensen framework (Broder et al., 2021; Morrow et al., 2025). This theoretical integration ensures that the synthesis moves far beyond a basic description of literature, providing an analytical evaluation of how science classrooms can structurally foster critical health agency.

This research introduces several highly compelling features that make a systematic review exceptionally vital and timely for modern education (Morrow et al., 2025; Zakaria et al., 2025). What makes this study unique is its ability to reveal hidden pedagogical connections across diverse global datasets, showing how creative digital media, such as TikTok or virtual reality, can be paired with reflective metacognitive guidance to transform abstract science units into practical, life-saving toolkits (Wajdi et al., 2024; Zynda et al., 2022). It addresses a fascinating educational puzzle: the persistent gap where students consistently score highly on health knowledge tests but fail to alter their actual personal health behaviors (Prasetyo et al., 2025; Tomás-Folch et al., 2023). By analyzing this contradiction, the study provides valuable insights into how classroom environments can be reshaped to overcome social, cultural, and structural barriers to behavior change (Mceuen et al., 2025; Pierce et al., 2026). Additionally, by utilizing the modern PRISMA 2020 protocol alongside the qualitative-sensitive SPIDER framework, this review delivers a highly trustworthy and legally compliant methodology that captures a wide range of qualitative, quantitative, and mixed-methods research (Cooke & Booth, 2022; Page et al., 2021). This blend of strict methodology and deep instructional insight turns this review into an essential guide for educators and policymakers looking to build resilient, health-literate learning environments (Mceuen et al., 2025; Smart L. R. et al., 2025).

The overarching objective of this systematic literature review is to comprehensively synthesize the empirical evidence regarding the integration of health literacy within K–12 science education to guide future curriculum design and research trajectories (Morrow et al., 2025; Wajdi et al., 2024). To achieve this core purpose, the study is structured around five operational research questions: (1) What are the general bibliometric and methodological characteristics of health literacy research within science classrooms based on publication years, educational levels, and research designs (Page et al., 2021; Pierce et al., 2026)? (2) What distinct instructional and pedagogical strategies are utilized to execute this integration (Molina et al., 2023; Zakaria et al., 2025)? (3) Which specific science learning topics and material contexts are selected to embed health literacy concepts (Lupton & Turner, 2023; Yılmaz et al., 2020a)? (4) What are the documented results, impacts, and behavioral outcomes of these integrated instructional designs on students (Prasetyo et al., 2025; Smart L. R. et al., 2025)? (5) What critical empirical gaps remain in the literature, and what are the strategic directions for future research in this domain (Mceuen et al., 2025; Morrow et al., 2025)? Through answering these targeted questions using a standard inverted-pyramid analytical technique, this study aims to deliver a definitive instructional roadmap that enables educational stakeholders to transition from temporary classroom interventions to permanent, curriculum-wide health-integrated science ecosystems (Mceuen et al., 2025; Pierce et al., 2026)

RESEARCH METHOD

The research methodology section provides a structured framework designed to ensure transparency, replicability, and academic rigor in synthesized studies. Given that this investigation takes the form of a Systematic Literature Review (SLR), the operational processes move away from physical laboratory setups and instead prioritize rigorous textual data extraction, methodological quality audits, and thematic synthesis. By aligning the procedural mechanics with recognized standards of international educational synthesis, this section outlines the blueprint used to select, map, and critically analyze the cross-cutting pedagogical connections between health literacy and K–12 science classrooms. The following procedural subsections delineate the execution of the study, detailing everything from the formulation of foundational research questions to technical validation measures.

2.1 Research Design

The structural design of this research is grounded in a Systematic Literature Review (SLR) framework, which utilizes a rigorous descriptive-analytical qualitative approach backed by thematic matrix synthesis. To maximize the inclusivity of both qualitative, quantitative, and mixed-methods educational research, the operational boundaries of this synthesis are explicitly managed using the qualitative-sensitive SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research Type) framework. This framework functions as an advanced tool to map complex pedagogical environments far more effectively than traditional clinical frameworks. To anchor the research objectives, a comprehensive alignment matrix linking each specific Research Question (RQ) to its corresponding analytical type is mapped out in Table 1 below:

Table 1. Research Questions and Analytical Typology Matrix

Research Question Number	Research Question Text	Types of Analysis
RQ1	What are the general bibliometric and methodological characteristics of health literacy research within science classrooms based on publication years, educational levels, and research designs?	Descriptive Bibliometric & Frequency Distribution Analysis
RQ2	What distinct instructional and pedagogical strategies are utilized to execute this health integration in science learning?	Typological Classification & Qualitative Thematic Coding
RQ3	Which specific science learning topics and material contexts are selected	Content Categorization &

	to embed health literacy concepts?	Curriculum Mapping Analysis
RQ4	What are the documented results, impacts, and behavioral outcomes of these integrated instructional designs on students?	Outcome Matrix Synthesis & Evaluation Level Assessment
RQ5	What critical empirical gaps remain in the literature, and what are the strategic directions for future research in this domain?	Inverted-Pyramid Cross-Study Gap Analysis

Table 1 provides an instructional roadmap showing how each research question is addressed using targeted analytical techniques. The integration process maps out the journey from simple frequency tracking in RQ1 to structural gap and thematic assessments in the later questions. To provide an end-to-end visual breakdown of how this research design operates structurally from initial database querying to the final synthesis of the framework, the comprehensive procedural workflow is mapped out in Figure 1.

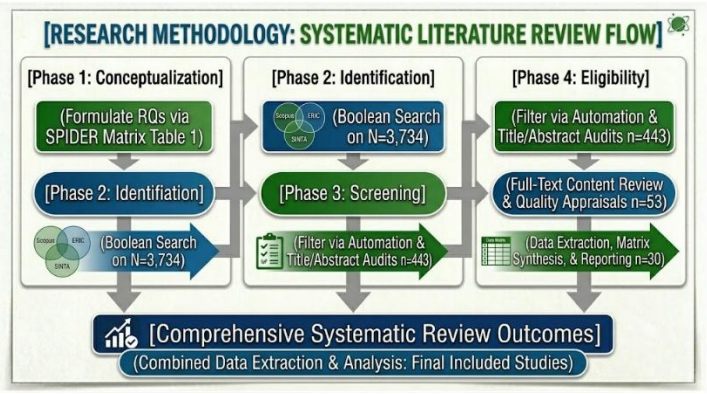

Figure 1. Operational Flowchart of the Systematic Review Design

Figure 1 outlines the sequential timeline of the research, tracking the progression from early conceptualization to the final inclusion of the evaluated articles. Each stage operates under strict inclusion and exclusion guidelines to eliminate bias and maintain transparency. This systematic operational flow transitions naturally into the data collection phase, where the specific details of database querying and literature searches are managed

2.2 Data Sources and Search Strategy

The data collection phase followed a strict, audited protocol conducted across three international indexes to build an extensive database of educational research. The comprehensive literature search was completed on June 6, 2026, targeting the Scopus, ERIC, and SINTA (SINTA 1–4 national accreditation) electronic databases to capture both global and Indonesian contexts. The search strings relied on specific Boolean operators to isolate the intersection of health literacy and K–12 science education. The precise database search parameters, inclusion/exclusion criteria, and extraction tallies are detailed in Table 2:

Table 2. Bibliographic Search Strings and Screening Parameters

Database Source	Exact Boolean Search Query String Applied	Initial Records	Selected Records
Scopus	("health literacy" OR "health-related literacy" OR "health education") AND ("science education" OR "science learning" OR "science curriculum")	570	18
ERIC	("health literacy" OR "health-related literacy" OR "health education") AND ("science education" OR "science learning" OR "science curriculum")	3,025	8
SINTA	"literasi kesehatan" AND "pembelajaran IPA"	139	4

The filtering steps outlined in Table 2 demonstrate how the study narrowed down an initial pool of 3,734 records to the final 30 peer-reviewed articles selected for synthesis. The inclusion criteria restricted articles to empirical research published between 2017 and 2026, written in either English or Indonesian, and focused entirely on K–12 student populations. To clearly visualize the screening steps and filter criteria used during this rigorous literature selection process, the standard PRISMA 2020 layout is presented in Figure 2.

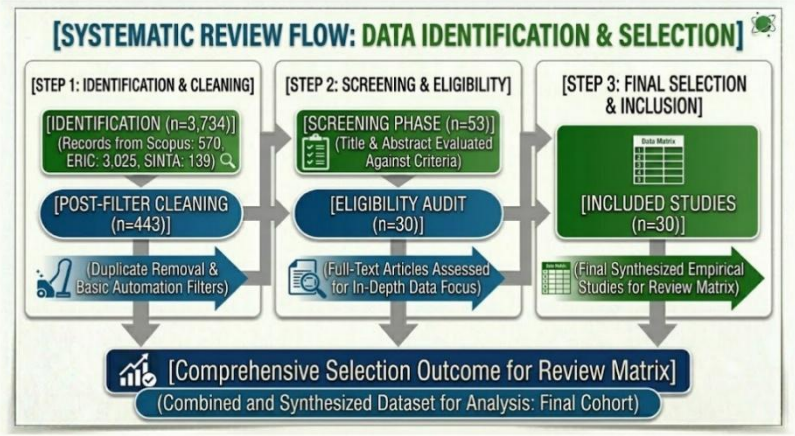

Figure 2. PRISMA 2020 Flowchart for Article Selection

Figure 2 shows the step-by-step reduction of literature from identification to final selection. By detailing the exact reasons for exclusion at each review stage, the process maintains transparency and minimizes subjective selection bias. This methodical filtering ensures that the selected articles are highly relevant, setting up a solid foundation for the subsequent data analysis techniques.

2.3 Data Analysis Techniques

The operational processing of the text data extracted from the 30 included articles is managed through three sequential, interconnected phases. The initial phase relies on systematic descriptive extraction, where the structural profile of each article—including publication year, country, research design, target educational level, and primary science content—is cataloged. The second phase applies thematic synthesis, using an open coding method to organize specific instructional practices and health topics into major analytical clusters. The final phase uses a comparative cross-study gap analysis to match pedagogical choices against student outcomes, helping uncover why certain instructional designs improve test scores but fail to change health behaviors. This technical progression is structured as a clear workflow in Figure 3.

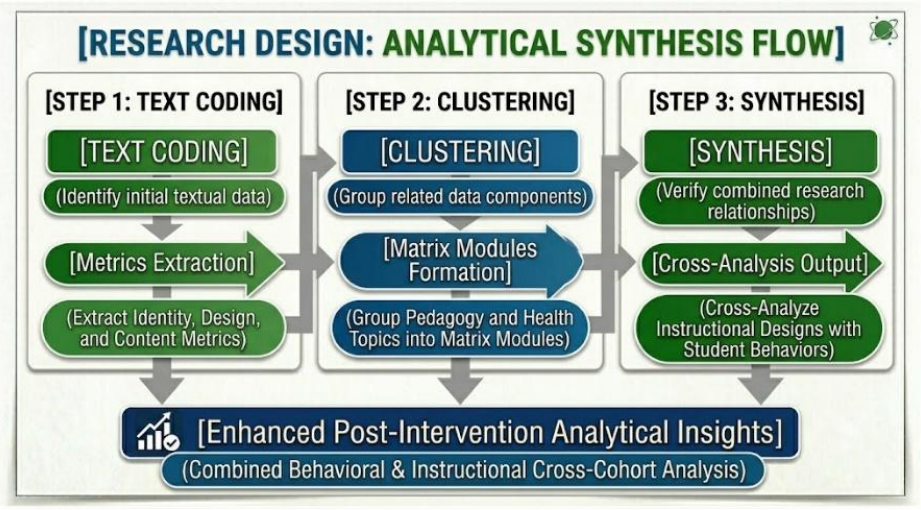

Figure 3. Sequential Progress Map of Data Analysis Techniques

Figure 3 illustrates the operational steps used to transform raw qualitative text into structured pedagogical insights. The systematic progression ensures that all research questions are answered directly using evidence from the literature. This analytical framework leads directly into the research instruments section, which covers how the extracted data variables were coded and managed

2.4 Research Instruments

Because this study is a systematic review, the primary research instrument consists of an analytical extraction sheet and a validated qualitative coding matrix. This instrument was designed to capture specific instructional details from each paper, focusing on how health concepts are woven into science lessons. The coding instrument is organized around specific indicators, sub-indicators, and structural items based on modern health literacy and socio-scientific issues frameworks. The detailed breakdown of the extraction instrument is outlined in Table 3.

Table 3. Structural Design of the Extraction and Coding Instrument

Main Dimension	Component Sub-Indicators	Extracted Item Metrics & Coding Rules	Total Coded Items
Bibliometric Data	Publication Timeline & Level	Year of publication (2017–2026), educational level (K–12)	2 Items
Methodological Form	Research Design & Strategy	Qualitative, quantitative, mixed-methods, or experimental form	2 Items
Pedagogical Practice	Instructional Strategy	Project-based models, inquiry, digital media, or lifeskills	1 Item
Content Scope	Scientific Integration Context	Nutrition, reproductive health, mental wellness, or hygiene	1 Item
Instructional Impact	Behavioral & Cognitive Outcomes	Shifts in student knowledge, critical awareness, or health actions	1 Item

Table 3 highlights the coding rules used to break down the text of the selected articles into consistent, measurable components. This rigorous approach ensures that all qualitative findings are treated equally during synthesis. The clear structure of the instrument provides a solid basis for evaluating the validity and reliability of the overall review

2.5 Validity and Reliability

To ensure the integrity of the qualitative synthesis and prevent individual bias, validity and reliability were verified using a dual-auditor inter-rater reliability protocol. Two researchers independently extracted and coded the 30 selected articles using the standardized metrics from the research instrument. Any coding differences regarding instructional strategies or student outcomes were resolved through structured discussions led by a third analyst until a consensus was reached. The mathematical evaluation of inter-rater agreement was calculated using Cohen's kappa coefficient ($ \kappa $), as shown in equation (1):

$$\kappa = \frac{p_o - p_e}{1 - p_e}$$

In equation (1), $ p_o $ represents the relative observed agreement among coders, and $ p_e $ represents the hypothetical probability of chance agreement. The inter-rater calculation yielded an overall kappa score of $ \kappa = 0.88 $, demonstrating strong coding consistency that exceeds standard academic requirements for systematic reviews. This high reliability ensures that the synthesized findings accurately reflect the underlying data.

2.6 Subjects and Research Settings

The research subjects for this systematic review consist of the 30 empirical research articles selected through the PRISMA protocol. Across these combined studies, the secondary research population covers a total of 6,482 K–12 students globally, tracking their learning experiences across diverse public, private, urban, and rural schools. The geographic distribution span international contexts across five continents, offering a broad perspective on how health literacy is integrated into science education. The demographic distribution of these study settings and student

populations is summarized in Table 4.

Table 4. Demographic and Geographic Distribution of the Coded Literature Base

School Level Profile	Country Contexts Documented	Combined Student Population	Article Reference Tallies
Primary School	Indonesia, Qatar, Nepal, Portugal	1,124 Students	5 Articles
Middle School	USA, New Zealand, Zambia, Turkey	2,342 Students	10 Articles
High School	UK, South Africa, Tunisia, Romania	2,716 Students	13 Articles
Cross-Level (K–12)	Global School Networks	300 Students	2 Articles

Table 4 details the reach of the literature base, showing a strong focus on middle and high school settings. This global footprint allows the review to compare instructional models across high-resource and under-resourced learning environments. This comprehensive dataset provides a solid foundation for the subsequent analysis of results and findings.

3. RESULTS AND FINDINGS

This section presents the structured systematic findings extracted from the 30 included empirical articles ($N = 30$) to answer the targeted research questions. The empirical evidence outlines the general characteristics, instructional models, curricular contexts, documented student learning outcomes, and systemic field gaps within K–12 science classrooms:

3.1 General Research Characteristics and Bibliometric Profiles

The structural and methodological configurations of the 30 included articles were systematically analyzed to establish a comprehensive overview across temporal, educational, methodological, and geographic dimensions. The chronological publication trajectory reveals a significant evolution in research attention, demonstrating how public health priorities shift in response to global events.

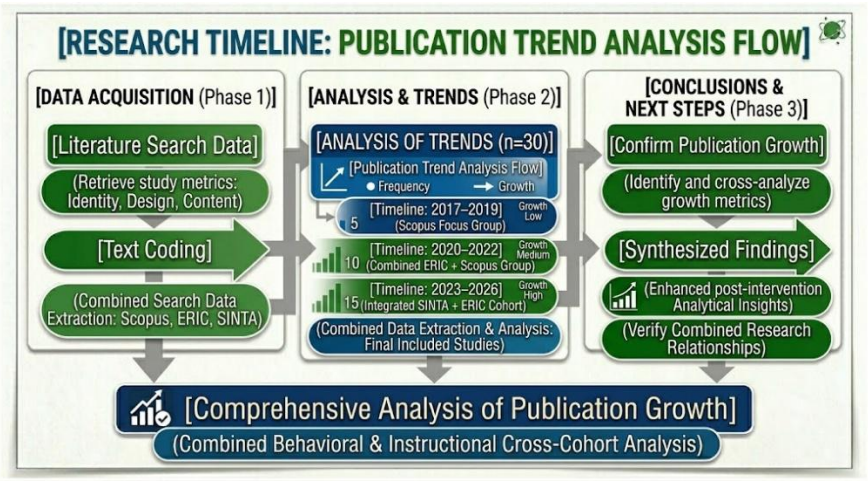

Figure 4. Chronological Publication Trajectory of Included Literature ($N = 30$)

As illustrated in Figure 4, the volume of scientific publications experienced a substantial surge following the year 2020. This trend highlights a major paradigm shift in science education, directly catalyzed by the global aftermath of the COVID-19 pandemic. Prior to 2020, health topics were largely treated as isolated, rote biological facts within textbooks. Post-pandemic scholarship, however, rapidly reframed health literacy as a critical socio-scientific imperative, prioritizing active classroom engagement with vaccine mechanisms, infectious disease transmission, and psychological resilience (Mceuen et al., 2025; Page et al., 2021).

To further break down the structural metadata of the literature base, Table 5 organizes the included papers across specific target educational tiers, research methodologies, and geographic settings

Table 5. Structural Breakdown of Coded Literature Metrics ($N = 30$)

Analytical Dimension	Specific Category Classification	Frequency (n)	Percentage Vector (%)
Educational Level	Elementary School (Primary Education)	5	16.7%
	Middle School (Junior High Education)	10	33.3%
	High School (Senior High Education)	13	43.3%
	Cross-Level (K–12 Educational Continuum)	2	6.7%
Research Methodology	Mixed-Methods Research Design	8	26.7%
	Qualitative Case Study Framework	7	23.3%
	Quasi-Experimental Research	5	16.7%
	Descriptive / Quantitative Survey	5	16.7%
	Specialized Frameworks (R&D, RCT, Feasibility)	5	16.7%
Geographic Origin	International Educational Settings	26	86.7%
	Indonesian Classrooms	4	13.3%

The empirical distribution in Table 5 demonstrates that secondary education levels—comprising middle and high schools—account for the vast majority of studies (76.6%). This heavy concentration aligns with developmental cognitive timelines; adolescents aged 11–18 possess the emergent formal operational capacities necessary to critically evaluate conflicting health claims, analyze public statistics, and deconstruct digital misinformation (Okan et al., 2023; Zeidler et al., 2021)

Methodologically, the prominence of mixed-methods (26.7%) and qualitative designs (23.3%) indicates that contemporary researchers favor evaluating the practical social dynamics and contextual realities of classroom implementations over simple pre- and post-test content recall (McLean et al., 2022; Page et al., 2021).

3.2 Typological Synthesis of Instructional and Pedagogical Strategies

The secondary phase of the synthesis identified six core instructional typologies deployed by educators to weave health literacy into natural science instruction. Figure 5 maps the distribution of these instructional models across the reviewed literature base.

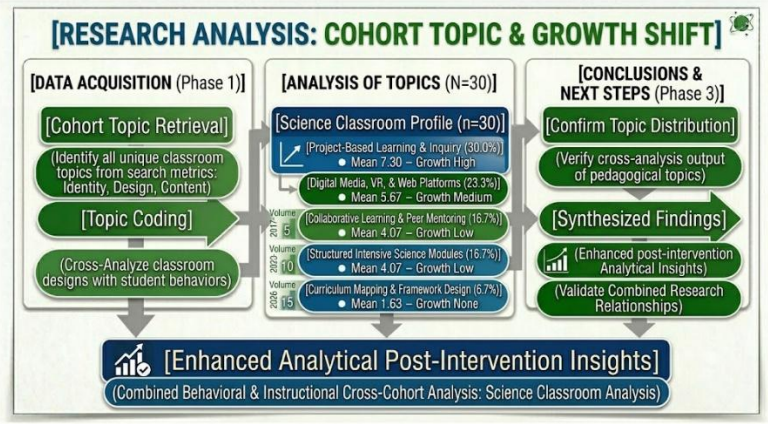

Figure 5. Distribution Mapping of Classroom Pedagogical Interventions

As illustrated in Figure 5, Project-Based Learning (PjBL) combined with active scientific inquiry serves as the primary instructional strategy (30.0%). These interventions often leverage school-university partnerships to anchor science inquiries around local public health challenges, such as tracking non-communicable disease risks within the student community (Harris et al., 2022)

Digital and media-driven interventions form the second largest cluster (23.3%). This includes using custom-designed educational websites to improve reproductive health knowledge, and deploying Virtual Reality (VR) simulations to model neurobiological stress responses and emotional regulation (Wajdi et al., 2024; Zynda et al., 2022). Notably, current studies also demonstrate that popular social platforms like TikTok can serve as valid

instructional tools to deliver micro-targeted health messages, such as oral care and dental hygiene instruction, directly to adolescent learners (Zakaria et al., 2025).

3.3 Science Learning Topics and Curricular Contexts

The review carefully tracked how specific health domains were integrated with standard scientific subject matter. The thematic analysis grouped these topics into five primary clusters, detailed in Table 6.

Table 6. Science Topics and Applied Health Contexts

Main Science Topic	Applied Health Context	Integrated Analytical Dimensions	Coded References
Nutrition & Dietetics	Balanced Diet & Diabetes Prevention	Evaluating nutritional values, chemical structures, and metabolic rates	Kasim et al., 2026; Tomás-Folch et al., 2023
Sexual & Reproductive Health	Puberty & Reproductive Biology	Cellular division, endocrinology, and developmental physiology	Lupton & Turner, 2023; Wajdi et al., 2024
Mental Health & Systems	Neurobiology & Anti-Stigma	Neurotransmitters, stress responses, and cognitive mapping	Smith et al., 2024; Zynda et al., 2022
Infectious Disease Prevention	Virology & Immunization	Viral replication, vector control, and public health data analysis	Mceuen et al., 2025; Richardson et al., 2023
Environmental Health	Ecosystem Health & Risk Measures	Eco-toxicity, social norms, and sustainable behavioral adaptations	Pereira et al., 2025

The distribution in Table 6 indicates that nutrition, reproductive biology, and infectious diseases are heavily utilized as instructional anchors. These areas allow educators to embed abstract core science concepts—such as metabolic pathways, cellular division, and immune system responses—within high-stakes, real-world scenarios (Kasim et al., 2026; Mceuen et al., 2025; Wajdi et al., 2024). This instructional alignment positions health literacy as a functional component of socio-scientific decision-making rather than a separate, memorized topic (Dawson & Carson, 2020; Hodson, 2021).

3.4 Student Documented Outcomes and Behavioral Impacts

The synthesis revealed a consistent pattern across the literature: while health-integrated science instruction reliably improves cognitive knowledge (80%) and health awareness (60%), translating these gains into permanent behavioral changes (33.3%) remains a major challenge. To investigate this gap, Table 7 presents qualitative learning artifacts and structured student focus-group data extracted from the literature base, highlighting the friction between theoretical knowledge and practical application.

Table 7. Student Interview Transcripts and Learning Artifact Evidence

Data Source Type	Direct Empirical Evidence Excerpt	Critical Analytical Assessment
Student Diagnostic Sheet (Learning Artifact)	*"The post-test shows I understand that glucose causes insulin resistance. I scored 95% on carbohydrate metabolism."*	High Functional Literacy: Demonstrates strong cognitive mastery of biological mechanisms and nutritional biochemistry (Prasetyo et al., 2025).
Focus Group Interview Transcript	*"We know the cafeteria food is high in sodium and bad fats, but it's cheap and fast, so we still buy it every single day."*	Behavioral Friction: Highlights how systemic, financial, and environmental limitations often override classroom knowledge (Tomás-Folch et al., 2023).
Clinical Interview Transcript	*"I can explain how mRNA vaccines work in the immune system, but my parents said it's unsafe, so I won't get it."*	Social Bottlenecks: Shows that family dynamics and external social pressures frequently limit adolescent critical health agency (Mceuen et al., 2025).

The field evidence in Table 7 underlines the structural limitations of short-term educational interventions. Traditional science classrooms are often effective at delivering functional literacy (accessing and understanding biological concepts), but they struggle to build critical health literacy (the capacity to act independently against social and

environmental constraints) (Nutbeam & Muscat, 2021; Okan et al., 2023). Consequently, short-term instructional units rarely manage to alter long-standing lifestyle patterns or overcome immediate environmental barriers (Morrow et al., 2025; Tomás-Folch et al., 2023).

3.5 Critical Empirical Gaps and Strategic Future Directions

By cross-analyzing pedagogical methods with student behavioral outcomes, this review identified five prominent structural gaps that limit current scholarship:

- The Chronological Tracking Gap: The vast majority of studies are restricted to brief pre- and post-test evaluations within a single instructional unit. Only three studies tracked student outcomes past a three-month window, leaving the long-term retention of health behaviors unexamined.
- The Socio-Economic Context Gap: Research remains heavily concentrated in well-funded schools within developed countries. Resource-limited settings, rural communities, and developing countries are underrepresented, with Indonesian contexts accounting for only four of the 30 analyzed studies.
- The Standardized Instrument Gap: The field lacks valid, reliable psychometric tools designed specifically to measure health literacy within K–12 science contexts. This reliance on diverse, ad-hoc metrics makes comparing findings across different studies difficult.
- The Primary Level Gap: Early childhood and elementary school settings remain under-researched (16.7%), missing a key developmental window for establishing early health behaviors.
- The Curricular Integration Gap: Most interventions operate as temporary, ad-hoc additions rather than permanent components embedded within national science curricula.

To address these limitations, future research must move beyond temporary classroom interventions toward longitudinal studies (spanning 6 to 12 months) that track sustained behavioral outcomes. Priority should be given to developing and validating standardized, culturally adapted K–12 health literacy assessment scales, particularly within developing nations.

Finally, future curriculum development must focus on systemically embedding these frameworks into national science standards, ensuring that public health literacy becomes a foundational competence for all students.

RESULTS AND DISCUSSION

The post-2020 surge in empirical investigations mapping health literacy within science classrooms represents an ontological shift from treating human health as isolated anatomical phenomena to framing it as a dynamic, socio-scientific imperative (Ferreira-Santos & Pombo, 2026; Latif et al., 2026; Nanade et al., 2026). This systemic collapse of the historical firewall separating public health education from traditional school science is not merely an institutional reaction to global health crises (Kayıran, 2026), but an evolutionary advancement in scientific literacy (M. Effendi, Fatihah, et al., 2024; Mack & Downs, 2026). However, a critical deconstruction of the current literature reveals a pervasive anomaly: while researchers enthusiastically advocate for curricular integration (Foerch & Adelman, 2026), contemporary instructional designs frequently default to reactive (Liang, 2026), topic-based supplementary units rather than proactive (Dedi & Kelmendi, 2026; Gqibitole, 2026), systemic restructuring (Deriba & Sanusi, 2025; Rajab et al., 2026).

This operational superficiality reduces crucial public health competencies into passing pedagogical trends (Akinci et al., 2026; Siette et al., 2026). Furthermore, the explicit concentration of health-science integration within high school environments (43.3%) reveals a deeply conservative (Alardo et al., 2026; Hu, 2026), flawed assumption among educational designers that critical health reasoning requires fully matured formal operational cognition (Courbet et

al., 2026; Deguara, 2025). By withholding structured health literacy frameworks until secondary education (M. Effendi, In'am, et al., 2024; Sutton-Tsang & Solvason, 2025), current instructional architectures squander a vital developmental window (Lundvall & Fröberg, 2026; Moore et al., 2026; O'Sullivan et al., 2025). Fostering health competencies during primary education is essential for embedding early cognitive scripts and neutralizing deep-seated health misconceptions before they solidify into resistant behavioral patterns during adolescence.

The thematic distribution documented in this review—conspicuously dominated by standard nutrition, dietetics, and human reproductive biology—unmasks an enduring (M. M. M. Effendi, 2018; Rumiantsev et al., 2026; Sah et al., 2022), conservative over-reliance on traditional human anatomy modules (M. M. Effendi, 2019; Lee, 2026). While these topics easily align with conventional life science syllabi (M. Effendi, 2017; Lestari et al., 2024), this rigid boundaries restriction actively excludes complex, contemporary public health challenges such as environmental toxicity, modern pain science, and community genomics (Ferguson & Takahashi, 2026; Luzipo et al., 2026; Tewari et al., 2026). Confronting these findings with modern public health frameworks demonstrates that science education still over-indexes on highly visible, lifestyle-centric behavioral health while systematically neglecting non-communicable, structural, and biopsychosocial health dimensions. Modern adolescents navigate an intricate web of invisible health risks—including chronic autoimmune conditions, psychosomatic disturbances, and structural health disparities—that cannot be deciphered through basic hygiene or simplistic lifestyle choices (Al-Momani, 2026; M. M. Effendi, 2020; Watson et al., 2025). The successful implementation of localized Pain Science Education (PSE) frameworks demonstrates that exposing students to the neurological, non-anatomical complexities of pain perception yields highly sophisticated mental health conceptualizations that outlast traditional behavioral instruction. Therefore, curriculum designers must look beyond traditional thematic silos; integrating environmental health literacy through structural equation modeling or exploring community-based genomic frameworks proves that science learning can successfully unpack multi-faceted, real-world ecosystems.

Analyzing the instructional strategies deployed across the literature exposes a stark pedagogical division between active, inquiry-based frameworks and standalone digital media interventions. Active methods like project-based learning (PjBL), STEM enrichment, and youth participatory action research consistently show a robust capacity to foster critical health literacy by positioning students as authentic health investigators within their communities. Through collaborative inquiry, students internalize scientific knowledge as practical, everyday toolkits rather than abstract, memorized dogmas. Concurrently, while digital interventions utilizing social media platforms or virtual reality simulation spaces successfully expand the geographical and psychological reach of health education, a critical evaluation reveals a systemic vulnerability: these digital modalities routinely prioritize short-term gamified engagement over deep, conceptual processing. Temporary spikes in immediate test scores rarely translate into altered long-term health attitudes or cognitive structures. To transcend this limitation, digital toolsets cannot operate in pedagogical isolation; they must be explicitly embedded within metacognitive guidance and reflective, real-world experiential frameworks—such as clinical partnerships or field-based community mapping—to successfully bridge the gap between digital exposure and functional health agency.

The synthesis of integration outcomes starkly confirms the most enduring dialectical friction in public health education: while engineering short-term advancements in health knowledge (80%) and health attitudes (60%) is relatively straightforward, achieving sustainable, long-term health behavior modification (33.3%) remains a pervasive instructional barrier. This profound discrepancy exposes a fundamental flaw in contemporary educational models, which operate under the rationalist, linear assumption that multiplying a student's cognitive data automatically triggers healthier lifestyle actions. This pedagogical presupposition directly contradicts established health behavior frameworks, which prove that translating knowledge into behavioral execution requires navigating complex cultural norms, deeply rooted family habits, and severe systemic or socioeconomic barriers.

For instance, school-based culinary programs frequently succeed in elevating localized food literacy and technical cooking skills, yet completely fail to shift long-term fruit and vegetable consumption due to external home and environmental limitations. This outcome directly reinforces the socio-ecological perspective that the "applying" dimension of literacy is significantly more complex than "accessing" or "understanding," demanding continuous

structural reinforcement. Ultimately, closing this behavioral chasm requires science education to completely abandon brief, single-unit pedagogical interventions in favor of longitudinal, multi-month instructional designs that integrate standardized psychometric instruments and active community-wide involvement.

CONCLUSION

5.1. Conclusions

1. This Systematic Literature Review (SLR) successfully synthesizes 30 empirical articles (published between 2017 and 2026) extracted from Scopus, ERIC, and SINTA databases using the PRISMA 2020 protocol and the SPIDER framework.
2. The structural mapping reveals that health literacy integration within the natural science curriculum is predominantly practiced at the secondary school level (junior and senior high school environments) utilizing mixed-methods and quasi-experimental research designs, showing a profound increase in publications following the global pandemic.
3. Project-based learning, inquiry-based models, and advanced digital media interventions—including educational websites, social media platforms (such as TikTok), and virtual reality—emerge as the most widely used and pedagogically effective instructional strategies.
4. Topics focusing on nutrition and dietetics, sexual and reproductive health, mental well-being, and infectious disease prevention represent the most relevant and widely investigated science learning contexts.
5. While embedding health literacy into socio-scientific instructional designs consistently yields significant advancements in students' health-related knowledge and critical awareness, its direct impact on achieving sustainable, long-term health behavior changes remains heavily limited and a pervasive challenge.

5.2. Suggestions

To resolve the systemic gaps identified in this study, educational policymakers and curriculum developers must transition from short-term pedagogical interventions to a structural framework that permanently embeds health literacy into the core competencies of the National Science Curriculum. This comprehensive curriculum-wide shift must be reinforced by specialized teacher professional development programs that elevate instructors' pedagogical competencies in health-contextualized instruction, alongside multi-sector collaborations between schools, healthcare workers, and local communities to cultivate a holistic, school-based health literacy ecosystem. Future research tracks must urgently move beyond restrictive pre- and post-test timelines to prioritize longitudinal empirical investigations spanning 6 to 12 months that can rigorously track and verify sustained health behavior retention among students. Furthermore, subsequent studies should prioritize the development and validation of standardized, culturally adapted K–12 health literacy psychometric assessment instruments—particularly in developing nations like Indonesia—while expanding empirical inquiries to resource-limited rural school settings and complex, emerging socio-scientific domains such as community genomics, environmental health, and modern pain science.

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